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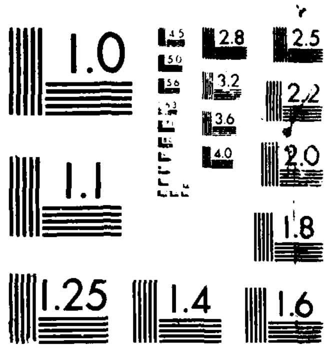
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This report summarizes accomplishments under a grant to study modeling, identification, and control of flexible structures and to study random fields with applications to laser beam distortion in a turbulent field. Research in flexible structures focused on deriving contiuum models based upon partial differential equations and derived methods for the solution of the resulting boundary control problems. A robust controller for stabilization based upon the abstract Hilbert-space demigroup formulation was derived as was a stochastic control theory for partial differential equations. A white noise theory for random fields was derived which has applications to laser beam

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THEORY OF FILTERING AND CONTROL WITH APPLICATION TO CONTROL OF LARGE SPACE STRUCTURES

Grant No.: AFOSR 83-0318

Principal Investigator: A.V. Balakrishnan

Period of Performance: 9/1/83 - 8/31/87

FINAL REPORT

March 1988

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This report summarizes the accomplishments of the research program during the period 9/1/83 - 8/31/87.

The bulk of the activity centered on two areas of Large Space Structure problem involving Filtering and Control:

I. Modelling, Identification and Active Control of Flexible Flight Structures

II. Random Fields: Laser Beam Distortion in a Turbulent Field

I. ACTIVE CONTROL OF LARGE SPACE STRUCTURES

1. PARTIAL DIFFERENTIAL EQUATION MODELLING

Focusing on the NASA SCOLE experiment [1], a multi-body model for Large Flexible Space Structures in terms of a continuum model described by partial differential equations with delta-functions on the boundary was developed in [2]. Several techniques of solution are described, the most comprehensive of which is the formulation as a nonlinear abstract wave-equation which clarifies the concept of modes for such "boundary control" problems. In particular it is shown that asymptotically as the mode number increases, the mode shapes approach for the "clamped-clamped" case. The importance of this result for practical application is underscored in [14].

A comprehensive model incorporating both the rigid-body slewing as well as the flexible mast stabilization is developed in a Ph.D. Thesis (Th. 1)

2. CONTROL DESIGN

A theory of active control design for rapid slewing while maintaining the required degree of mast stability is described in [3]. A robust controller for stabilization based on the abstract Hilbert-space semigroup formulation is derived in [4], [5].

A stochastic Control Theory involving partial differential equations is presented in [6] covering co-located sensors and actuators. A noteworthy feature here is a "multicriteria" otpimization problem of increasing the damping while simultaneously decreasing the noise contribution in the chosen modes.

The effect of the saturation-type nonlinearity in practical actuators (e.g., reaction jets) is studied in [7] leading to a theory of robust nonlinear controllers. Here the problem formulates as a nonlinear wave-equation where the nonlinear is not Lipschitzian and hence needs special treatment.

The antenna slewing problem must take into account the kinematic nonlinearity characteristic of rigid body rotation. A new stochastic problem that has arisen in this context is that of characterizing the response of a rotating rigid body to random torques. The corresponding stochastic differential equations are nonlinear and non-Lipschitzian and special techniques have to be used for constructing the solution for given white noise (or Wiener process) sample paths. The solution [10] displays some novel features in the axially symmetric case -- the asymptotic first-order distribution turns out to be Gaussian, and the second order is nearly Gaussian. The spectral density is non-rational and the bandwidth is always larger than that indicated by the damping term. The relation to Guassian mixtures is explored in [12].

II. The problem of characterizing damping is long recognized as difficult. In [8] it is shown that in the partial differential equation model all the hitherto linear models proposed such as asymptotically proportional damping can be subsumed by requiring that the semigroup generated -- in the abstract Hilbert space wave equation formulation -- be analytic. In particular it is shown that this is satisfied for the "strictly proportional" damping model by taking the square root of the "spring constant" operator. The requirement of analyticity has also the added advantage that the <u>modal</u> representation of the solution is valid even if the modes are not orthogonal and continues to hold under perturbation by the feedback control operator. This is a truly partial differential equation phenomenon not observable for finite element models.

Another important nonlinear phenomenon discovered in the SCOLE study is the need to take into account the nonlinearity in damping especially at high amplitudes. A new class of damping models including hysteresis has been introduced in [11] in the context of hyperboilc partial differential equations. Initial calculations show qualitative agreement with SCOLE data.

We may observe in conclusion that this four-year study has helped to initiate the systematic use of partial differential equation models for Identification/Control problems for flexible structures. It has played a significant role in putting to rest once and for all the following oft-stated obstacles preventing the use of partial differential equation models: viz.:

a) ability to model realistic spacecraft structures

b) accuracy and computational burden in generating solutions

c) difficulty in synthesizing control laws

d) lack of adequate theory of system identification

e) lack of adequate damping models.

RANDOM FIELDS

A fruitful area of application of the Principal Investigator's White Noise Theory for Random Fields (involving partial differential equations) was the problem of Laser beam propagation in the atmosphere -- in particular the characterization of the wave front distortion due to turbulence. This problem has a wide potential area of applications: Adaptive Optics (automatic correction of wave front distortion by deforamtion of mirror surface using actuators, for tracking and/or directed energy) and Fiber Optics (shaping index of refraction of the fiber).

The main problem here is the modelling of the turbulence field: in the so-called Markov model the field is "delta-correlated" in the direction of propagation. This has been interpreted in the pure mathematics literature as a "Wiener process" and then an ad hoc Stratarovich correction term added at the end. We show in [9] that the White Noise formulation is more appropriate, yielding the correction term naturally, and in particular allowing for the physically meaningful "large bandwidth" notion. A complete solution including the characterization of the (limiting) correlation (coherence) function has been obtained in [9], clarifying the smoothness properties required and the appropriate function-space setting. A digital computer simulation verifying the White Noise Theory is in progress [Th. 2], in which the nature of the approximation as a function of the increasing bandwidth is a major concern.

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